Bulletin No. 67 1916

Agricultural Research Institute, Pusa

Third Report on the Improvement of Indigo in Bihar

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CALCUTTA
SUPERINTENDENT GOVERNMENT PRINTING, INDIA
1916

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Third Report on the Improvement of Indigo in Bihar

I. INTRODUCTION.

WHEN the Indigo Research Station at Sirsiah was closed on March 31st 1913, investigations on the agricultural and botanical aspects of this industry were taken in hand by the Botanical Section of the Agricultural Research Institute at Pusa. Two reports on the results obtained have been published. In these papers[1] reference was made to the importance of soil-aeration and drainage in the cultivation of indigo and also to the part played by the root-nodules in the general economy of the plant. While it is true that the views put forward have excited a great deal of interest and have been accepted by many, nevertheless it has become apparent that a few of the indigo planters in Bihar have not altogether grasped the full significance of the ideas running through these two reports. This applies in particular to the wilt of Java indigo and to its somewhat erratic occurrence in North Bihar. Our investigations clearly point to the conclusion that wilt is a starvation effect due to interference with the work of the roots and root-nodules and has arisen as a result of the continuous selection of late types in the Java mixture due to the methods in vogue in raising seed. The Pusa investigations also indicate that the natural indigo problem is largely a matter of soil-aeration and that the root-nodules play a very important part in the synthesis of *indican*.

The opportunity offered by the publication of this report has been taken to re-state, as clearly as lies in our power, the principles on which the cultivation of a leguminous plant like indigo depends and the conditions under which wilt is likely to occur. At the same time, the work in progress and in contemplation have been dealt with while in the chapter on the improvement of indigo the question of selection has been discussed in detail. It is hoped that the position of the natural indigo industry as a whole will now be clearly understood; that the various lines of investigation will fall into their proper perspective; that the difficulties still to be overcome will be realized and that all concerned—planters, merchants, Government and investigators—will unite their

[1] These reports were issued as Bulletins 51 & 54 of the Agricultural Research Institute, Pusa.

forces so as to place the industry on a firm and prosperous foundation. While we are convinced that this is possible, we are equally certain that no lasting good can possibly be accomplished till the working conditions of the indigo plant (the natural factory) are placed on a footing comparable with those which exist in the works in which synthetic indigo is prepared. So far, the plant has lost in the struggle with artificial indigo because one of the essential raw materials—air—needed in the natural synthesis of *indican* has been a limiting factor. The removal of this limiting factor is the first condition of progress in the resuscitation of the natural indigo industry in Bihar.

II. THE PRINCIPLES UNDERLYING THE PRODUCTION OF NATURAL INDIGO.

1. The Factors.

The species cultivated. The two species of indigo cultivated in Bihar, known as Java and Sumatrana indigo, are leguminous plants on the roots of which nodules occur. Sumatrana is a comparatively shallow-rooted annual while Java indigo is deep-rooted and behaves, in localities where the soil conditions are favourable, as a perennial. The range in time of maturity of the types constituting the Java crop is very great—some are early, others are very late and all intermediate stages occur. It is probable therefore that the root-range of Java indigo is not uniform. The early types are likely to be comparatively shallow-rooted while the late types have much deeper roots.

Soils. The soil of North Bihar in which indigo is grown belongs to the older alluvium of the Gangetic plain. Its main characteristics from the point of view of the plant are its depth, the uniformity of its fine particles, its water-holding capacity during the hot weather, the comparative nearness to the surface of the sub-soil water and the low content of oxygen in the deeper layers as shown by the analysis of well-waters. The indigo soils easily run together on the surface after rain forming a well-defined crust known to the cultivator as the *papri*. The formation of this crust is exceedingly harmful to crops, including indigo, as it interferes with the aeration of the soil.

The Bihar alluvium is not uniform. The high lying lands on which indigo is grown are generally lighter and opener in texture than the low-lying rice areas. The soil of the high lands themselves, particularly near rivers, is often made up of alternate strata, loamy and sandy in character. These facts are of importance when considering questions connected with soil-aeration and the root-development of indigo.

Climate. The climate of this region is well known. There is a well-marked cold season, in which the average rainfall is comparatively small, followed by the hot weather in March, April and May during which dry west winds are common leading to a great loss of sub-soil moisture and a corresponding amount of soil-aeration. In the monsoon phase, which lasts from June to early October, there is heavy rain (the amount and distribution of which varies greatly) sometimes accompanied by floods which kill out large areas of indigo. Wilt occurs during the monsoon, generally after the first cut is taken in June and July.

These are the main factors which must be borne in mind when considering how the cultivation of indigo can be improved. The details with regard to the ordinary cultivation of Java and Sumatrana indigo are so well known that a knowledge of these processes on the part of the reader is assumed.

2. The two nitrogen cycles in Indigo.

Indigo is grown for the sake of the *indican* in the leaves. This is a complex nitrogenous substance which yields indigo when the cut plant is steeped in water. *Indican* is manufactured by the plant from simple substances. As it contains nitrogen, the sources from which the plant obtains this element are important.

There are two nitrogen cycles in leguminous plants like indigo or, in other words, two sources from which this essential raw material can be obtained. The usual source is the atmospheric nitrogen fixed by the root-nodules. In addition, leguminous plants can use for growth, partly or entirely, the nitrates which occur in the soil. On very poor land, leguminous plants make use of the nodules only. On very rich land, they often utilize the soil nitrates exclusively. On land intermediate in fertility, both sources may be employed simultaneously.

Root-nodules. The nodules are rounded swellings on the roots of indigo which are formed soon after the seedling stage. They vary in size but are generally larger than a Sumatrana seed and can best be seen when a young indigo plant is taken up with a ball of earth and the soil carefully washed away with a watering can. Many of the nodules then remain attached to the roots as rounded, pinkish swellings. The nodules arise as a result of the invasion of the young roots (by way of the root hairs) by a certain soil organism (*B. radicicola*), the presence of which stimulates local root growth to such an extent that a swelling is formed. The invading organisms rapidly increase in numbers inside the nodule from which they derive, among other things, large quantities of carbohydrate food. This is manufactured by the leaves. The general opinion is that the organisms and the leguminous plant live together

in partnership to the advantage of both. The plant feeds the organisms while they, in return for food and lodging, assimilate nitrogen gas and build it up into complex substances which the plant can use in the formation of the proteids necessary both for ordinary growth and for the formation of flowers and seeds. The greatest development of nodules occurs just as the plant begins to flower. During this period, many of the nodules lose their substance and become little more than empty shells. It is commonly believed that the contents of the nodules are at this stage absorbed by the plant and are used up for the preparation of the large quantities of proteid required to form flowers and ripen seed. The seeds of the *Leguminosae* are always rich in proteids (1 to 9 per cent. of the dry weight is nitrogen) and indigo is no exception to the rule. In addition to water and carbohydrate food, the nodule organisms require oxygen which is also provided by the plant. This is one of the reasons why good soil-aeration is so necessary for leguminous plants like indigo. The active portions of the root, including the nodules and their organisms, breathe like animals do and so use up oxygen and produce carbon dioxide. The nodules also require free nitrogen gas and are of no use to the plant when they are immersed in water.[2] Nitrogen gas must therefore enter the nodules themselves if it is to undergo fixation. This can only happen in a well-aerated soil as the great source of nitrogen is the atmosphere.

The nitrate cycle. Nodules although common on the roots of leguminous plants are not essential for their growth. These plants are able to grow without the nodule and also to flower and form seeds. They are able to use nitrates dissolved in the soil water as their source of nitrogen. The plant can use both cycles at the same time and derive part of its nitrogen from the soil in the ordinary way and part from the nodules. Nodules are best developed in poor, open soils which are well-aerated. In well-manured soils rich in nitrates, leguminous plants tend to form few nodules and, if the soil is rich enough, none at all. It is possible therefore in the case of indigo to raise crops on very rich land which make no use of the nodule nitrogen cycle but which obtain all their nitrogen as nitrate from the soil.

These are the main facts relating to the nitrogen cycles of a leguminous plant like indigo. For the sake of clearness, the essential points are recapitulated as follows :—

(1) Leguminous plants like indigo can obtain their nitrogen in two ways—from the root-nodules or from the nitrates

[1] Frank, *Ber. d. Bot. Ges.*, 1892, p. 271.

[2] Nobbe and Hiltner, *Versuchsstationen*, 52, 155, 1899.

in the soil. Both these methods are often employed by the plant simultaneously.

(2) The nodules make use of nitrogen in the gaseous condition and build this up into substances which the plant uses for growth and for flower and seed formation.

(3) The nodules can only do their work properly in well-aerated soils as they need both nitrogen and oxygen as gas.

(4) Nodules are only abundant when leguminous plants are grown in poor, well-aerated soil. In rich soil, such as land full of *seeth* or saltpetre, they are only sparsely developed and, if the soil is rich enough, may not be formed at all.

3. The production of colour.

The general relation between the nitrogen cycle and the production of *indican* must now be considered. In this connection, the following facts have to be taken into account :—

(1) *The contraction of the area under indigo on the Gangetic alluvium.* Formerly, there was a considerable area under indigo in Lower Bengal and the United Provinces in addition to North Bihar. With the gradual decline in the industry, the area under indigo in the tracts outside Bihar rapidly diminished and the industry only maintained itself to any extent in North Bihar chiefly on certain estates which suit the crop. The contraction of the area in North Bihar itself is significant—the cultivation has been abandoned on the heavy, badly-aerated soils of the submontane tract and on estates subject to inundation and where the soil is heavy and surface drainage is poor. On such lands, disused indigo factories are unfortunately common. Indigo in Bihar has usually survived only on well-drained, high-lying factories where the aeration of the soil is above the average.

(2) *The situation of the estates which produce the best colour.* The reputation of the various Bihar estates for colour is well known in the trade and also among the planters themselves. Other things being equal, the best marks come from high-lying, well-drained areas and the worst cakes are made from indigo growing on heavy, badly-aerated lands. There is a well marked connection between the class of soil and the reputation of the estate for colour.

(3) *Heavy dressings of seeth stimulate the indigo plant but do not increase the yield of indican.* The connection between the yield of green plant and heavy dressings of *seeth* are well known. This manure produces abundant growth but the yield of indigo given by every 100 maunds of green plant is not so high as in the case of the produce of poor land. Speaking generally, *zilla* indigo, grown on the comparatively poor lands of the *ryots*, gives a better yield of dye than *zerat* indigo from lands which are manured with *seeth*. *Seeth* is a manure rich in combined nitrogen.

(4) *The colour produced in the nodule nitrogen cycle is superior to that of plants grown in heavy rich soil bearing few nodules.* This has been observed several times at Pusa. If leaflets taken from plants with abundant nodules and also from indigo growing in heavy, rich soil with few nodules are made to deposit their indigo in the leaflets themselves, great differences are apparent. The plants in the nodule cycle yield abundant bright blue indigo, those in the nitrate nitrogen cycle yield a very dark product almost black under the microscope. The differences correspond closely with the appearance of good and inferior indigo cakes.

The above facts all fall into line on the assumption that the production of good colour depends on the activity of the nodule nitrogen cycle and takes place to the greatest extent on the high-lying lands where soil-aeration is suitable for this process. Where the nitrate cycle predominates, as on low-lying damp tracts where the soil is rich and where nodules are not formed in abundance, indigo generally yields heavy crops of leaf with a low percentage of *indican* and cakes of poor quality.

The *indican* in the plant appears to represent the difference between the total nitrogen assimilated and that used for growth and may be regarded as a reserve which can be made use of under certain conditions. Thus Rawson found in Bihar that premature flower and seed formation was associated with a distinct falling off in *indican*, a result which supports the idea that this substance can function as a reserve material. Bergtheil in the Sirsiah Report for 1908-09 (p. 16) refers to this matter in the following words:—"The *indican* content of the leaf of those indigo yielding plants which have been studied (*I. arrecta* and *Sumatrana*) is known to drop as soon as the seed sets and to decrease gradually as the seed forms, so that it seems probable that it is drawn upon to assist in the process of seed formation." In the Sirsiah Report for 1907-08

(p. 15), particular attention is drawn to the fact that "plant grown under minimum moisture conditions has invariably a high colour content." Under such circumstances, there is nothing to interfere with the aeration of the nodules and the rapid production of *indican* goes forward undisturbed. The physiology of *indican* and of the other glucosides met with in leguminous plants is still obscure and much also remains to be done in working out in detail the nitrogen assimilation in this order. However, the connection between *indican* production and the nodule cycle in the case of indigo is supported by all the facts and experience available at the moment. It also derives considerable confirmation from the conditions necessary for growth in the case of gram [1] and the geographical distribution of this crop in India.

4. The manuring of indigo.

As the production of *indican* in the plant is bound up with the efficiency of the nodule nitrogen cycle, the question arises—Can we increase *indican* production by any form of manuring? This is one of the subjects to which great attention has already been paid in Bihar and the older reports abound in accounts of manurial experiments. The only definite fact which emerges from these trials is that nitrogenous manures like *sceth* stimulate the growth of the plant but do not increase the total amount of indigo per acre. The results obtained with the various artificial manures, on the other hand, are exceedingly contradictory and by a judicious selection of the evidence it would be possible to prove anything from the published figures dealing with these experiments. All this is at once explicable if due weight is paid to the existence of two nitrogen cycles in indigo and to the fact that unless the experimental plots are perfectly graded and surface-drained, local water-logging (by interfering with the work of the nodules) would be sure to upset any paper scheme of manurial experiments however well designed.

It is a curious circumstance that no attention has hitherto been paid to the only manures likely to be of use in indigo cultivation in Bihar namely, aerating agents like potsherds (*thikra*), brick refuse (*surkhi* and *rorus*) and charcoal (*koila*). Of the previous investigators, Rawson came nearest to the discovery of the connection between soil-aeration and the production of colour. In his *Report on the cultivation and manufacture of indigo*, 2nd Edition, 1907, p. 7, in dealing with Bihar soils he states:—

"Sample No. 13 is described as an old saltpetre soil, and one would therefore expect it to contain a high percentage of nitrogen, but on the contrary it proved, on analysis, to contain a very small amount of that

[1] *Memoirs of the Dept. of Agr. in India* (*Botanical Series*), vol. VII, no. 6, 1915.

element. Indigo plant grew upon this soil exceedingly well, and the colour obtained from it was of high quality. The chief feature about the soil, as revealed by analysis, was its high percentage of available as well as *total* phosphoric acid."

The saltpetre soils are well aerated soils and generally contain *thikra* or *roras* in abundance. In such land, indigo grows remarkably well and the colour in the leaf is abundant and of good quality. It might, therefore, be found to pay to add permanent aerating agents to the land. Experiments in this direction are already in progress at Pusa and on the Dholi estate and so far the results are promising. It remains to be discovered however what is the most economic amount of these dressings to apply and also the best state of division to which these materials should first be reduced. The results already obtained on some of the Pusa plots seem to indicate that these aerating agents should be applied in comparatively small fragments. The economic aspect of such manuring can of course only be discovered on large scale plots. Two other aspects of this manuring are likely to be important. In the first place, the door will be opened to the study of intensive indigo cultivation and the production of large quantities of indigo from small areas. In the second place, aeration is likely to tend to produce indigo of uniform dyeing power and therefore to help in the standardization of the natural product.

III. INDIGO WILT.

Indigo like several other leguminous crops is apt to be affected by wilt. The deep-rooted Java species is much more liable than the shallow-rooted Sumatrana. The trouble occurs, as a rule, during the second half of the monsoon phase usually after the first cut has been taken.

The characteristics of indigo wilt. The unhealthy condition of Java indigo, locally known as wilt, is unfortunately so well understood in Bihar that only the briefest description of the affected plants is required. The trouble usually begins after the first cut and can be observed first in a few plants scattered through the field. In many cases, this unhealthy condition spreads rapidly until the whole area becomes affected. Such fields do not recover and the crop gradually dies out.

The external symptoms of wilt are quite definite a slowing down of growth, followed by leaf-fall and a gradual change in the colour of the remaining foliage from the ordinary bright-green to a yellowish-green slaty colour. Afterwards, the plant dies off in stages, the process taking place slowly a branch at a time.

All the indications point to root trouble which further examination confirms. The main roots of the wilted plants are healthy but there

is a great lack of feeding roots and practically no nodules. The wilted plants are in reality starving in the midst of plenty on account of the fact that they can no longer assimilate atmospheric nitrogen and absorb water and other minerals from the soil. The main indigo roots, although uninjured, are unable, during the monsoon phase, to renew their root system and to form new nodules. This want of the power of repair in leguminous plants is well known and has been described previously.[1]

The occurrence of wilt. Wilt has been observed to occur on Java indigo under the following circumstances:—

(1) On the ordinary leaf crop during the monsoon. This is the indigo wilt as usually observed on indigo estates after the first cut in June or July. As a rule, it occurs during the second half of the manufacturing season. Its extent varies greatly according to the season. In some years, a few plants here and there may be wilted, in other seasons it is widespread and may cut short *mahai* altogether.

(2) On indigo sown in June at Pusa on well-drained land containing numerous potsherds. In 1912, Java indigo was sown in lines on *thikra* plots at the break of the monsoon. Practically the whole crop died of wilt by the middle of October. In one plot, a few blank spaces remained in the lines which were filled up by re-sowing in the first week of August, by which time the standing crop was badly affected by wilt. The August sown plants were not affected but grew well and gave heavy crops of well-ripened seed. Here healthy and wilted plants were growing next to next with interlocking root-systems. In no case, however, did wilt spread to the late-sown plants thereby indicating that wilt is not a disease in the ordinary sense.

(3) On old branches left at the first cut. If a branch is left at the first cut to carry on the transpiration current, it is observed that the indigo shoots much more quickly than if cut back to the ground. In some seasons, when the new growth is well-established near the ground, the old branch left begins to show signs of wilt which does not spread to the new growth. We have, in such cases, the phenomenon of a plant healthy below and diseased above.

(4) On indigo sown for seed in August and cut back in the middle of October. If young and healthy seed indigo in a vigorous condition is cut back to the ground level in

[1] Pfeffer, *Physiology*, vol. 1, 1900, p. 401.

mid-October when about a foot to eighteen inches high, most of the crop dies but some of the stumps produce a few wilted shoots. There is no question of damage by rain under such conditions and wilting here takes place on plant in perfect health. If such wilted plants are examined, it will be found that the nodules and feeding roots are dead. The main root is unable to repair itself and to form new nodules.

These are the four circumstances under which wilt has so far been observed. They must be all considered together when the question of the nature of this trouble is discussed.

The nature of wilt. A careful consideration of all the circumstances connected with the observed occurrence of wilt suggests that we are not dealing with a disease in the ordinary sense but with a starvation effect due to interference with the work of the nodules and fine roots. In the second half of the monsoon, wilt occurs because the soil has become water-logged and its porosity has been ruined to such an extent that the nodules and fine roots have been destroyed. In the case of the plot at Pusa where all the June sown plants were wilted while those sown in August were without exception healthy, the explanation is to be found in the fact that the root systems of the latter were still shallow and had not, before the end of the monsoon, reached the water-logged sub-soil in which the roots of the June plants had for some time been forced to exist. The occurrence of wilt on old branches left at the first cut is no doubt due to the fact that the branch has been starved by the new vigorous shoots on the line of communications which have absorbed most of the materials coming from the roots. In such a case it would be possible for wilt to occur on one part of the plant without the destruction of the nodules. The wilt which occurs on healthy August sown plants cut back in mid-October probably arises from the direct starvation of the nodules. At this stage, little or no reserves have been laid down in the main root and in the base of the stem. At the same time, the removal of the stem and leaves cuts short the food supply of the nodule and starvation results. In most cases, the nodules and fine roots die in a few days and no new shoots are formed. In some instances, the stumps are able to produce a few weak wilted shoots and the plant may linger on during the cold weather. In all such plants examined, nearly all the nodules were dead and the remainder were discoloured.

A consideration of these facts leaves little doubt that wilt is a starvation effect. If it were a disease, the organism connected with it would have to be isolated and the disease reproduced in inoculation

experiments. So far this has not been accomplished. If wilt is a disease, an explanation will have to be found of the occurrence of the wilted June sown plants and healthy August sown plants growing side by side at Pusa in 1912.

The distribution of wilt is sometimes exceedingly erratic. On this account, some planters have experienced difficulty in understanding that it is a starvation effect. Indigo on light, high-lying lands may suffer severely from wilt while the crop growing on heavy, badly-drained, water-logged land near may either escape altogether or may be affected only to a slight extent. At first these facts appear to contradict the view that wilt is a starvation effect often caused by water-logging. If this is so, it is argued that there should be less wilt on the high lands and more on the badly-drained, low-lying, water-logged fields.

Such cases are easily explained if all the facts of the case are taken into consideration. The chief fact to remember is that indigo can do without the nodule cycle and can make use of nitrate nitrogen. This is most likely to happen on low-lying, rich, moist soil somewhat close in texture such as that which is often cultivated during the hot weather by the people for their food crops. In such situations, few nodules are formed and indigo will live with its roots immersed in water provided the supply of oxygenated water, nitrates and other dissolved salts is adequate. To all intents and purposes the indigo would be growing as in water culture and no damage would result from long immersion. Indigo using the nitrate cycle on heavy land can therefore often live for a time when the land is under water. The case of indigo using the nodule cycle on high-lying, light land is quite different. The nodules die comparatively quickly when the air-supply to the roots is cut off by long continued rain. The nitrate cycle cannot be used as the light soils are often poor in this substance during the rains. Further, the indigo plant under such circumstances has lost the power of repair and cannot form new nodules. The result is wilt. The presence of a few wilted plants in a field which is not followed by the spread of the trouble is explained by the fact that some types of Java plant are much deeper-rooted than others. The incidence of wilt will naturally depend on the distribution of the root-system.

The extent of wilt in any one year or on any particular estate depends on a variety of circumstances and it is not always possible to correlate the amount of the damage done with the rainfall. Wilt will only become important when the aeration of the soil is completely destroyed for some time. This naturally depends on other things besides the total rainfall. The amount of air in the soil at the beginning of the monsoon will vary with the previous monsoon, the winter rainfall, the occurrence

of west winds and the amount of the hot weather rainfall. Generally speaking, a dry hot weather and long-continued, west winds will be factors tending to lessen wilt. A damp hot weather with east winds will have the reverse effect. During the monsoon, the distribution as well as the amount of rainfall is important. Heavy falls with long breaks often destroy the soil-aeration less than a constant succession of showers all of which are absorbed. The rise of the sub-soil water level is another factor. The nearer this gets to the surface the less the air in the soil and the quicker does complete water-logging occur.

The spread of wilt in Bihar. When Java indigo was first introduced into Bihar, it did exceedingly well and was noted for its rapid growth and general robustness. After a few years it seemed to slow down in growth and wilt began to appear. The crops kept for seed yielded less and less and soon the seed-problem became acute. Between 1910 and 1914, the area under Java indigo in Bihar decreased from 70,000 to about 15,000 bighas largely on account of wilt and the difficulty of obtaining seed.

The explanation of these facts is a matter of considerable interest both from the practical and scientific standpoints. The principal cause of the degeneration of the plant is undoubtedly to be found in the methods in vogue in Bihar in growing seed. It used to be the custom to keep the old leaf crops for seed. For a time, good crops of seed were obtained and it was not till some years had elapsed that the Java crop began to show signs of want of vigour and finally began to die of wilt. The degeneration was progressive.

The explanation of the falling off of vigour is a simple one if two facts are borne in mind. Firstly, Java indigo is exceedingly mixed and contains early, intermediate and late types. The early types are comparatively shallow-rooted while the late forms have deep roots. Between these extremes all gradations occur. Secondly, indigo does not set seed in Bihar till after the middle of October and the flowers which open before this period only give rise to empty pods. This is due either to the dampness of the air affecting the pollen, to the absence of bees or to both these causes. Every planter must have noticed that when a Java leaf crop was kept on for seed that many pods were formed in September and early October which contained no seed. The early plants gave little or no seed and the main seed crop was obtained from the late-flowering types. It requires little imagination to understand the cumulative effect of this unconscious selection. The early, shallow-rooting, quick-growing types would slowly become eliminated and the late deep-rooting, slow-growing types flowering after mid-October would tend to predominate. In the course of a few years, the botanical

constitution of the crop would change. The Java crop would become more and more made up of slower-growing, deep-rooted types. It is just these deep-rooted forms which in an alluvial soil like that of Bihar would, during the monsoon phase, be apt to be attacked by wilt. Shallow-rooting, quick growing kinds would be much less liable. The main cause of wilt is undoubtedly the unconscious selection exercised by the old method of growing seed. There are also two contributing causes to be mentioned—the gradual rise in the high flood level and wet seasons. These, however, are of minor importance compared with the alteration in the botanical constitution of the crop.

Remedies. It will be seen from the foregoing that no remedy can possibly be devised to cure an indigo plant affected by wilt. While cure is out of the question, prevention is not a difficult matter. Two things are necessary to achieve this object which will not only reduce wilt to insignificance but also increase the yield of indigo per acre.

(1) The Java crop must be brought back to its original condition. Instead of making the crop later and increasing the depth of its root-system by eliminating all the early plants, we must work in the opposite direction and select for earliness, rapid growth and shallow roots. The old method of growing seed must be given up and a special August sown crop grown instead. All weak, late-flowering plants in this seed crop must be cut out and destroyed and only the early-flowering kinds must be left. The seed crop must be rogued twice every year—once before flowering begins and again when it is well in progress. Every weak-looking, late-flowering plant must be ruthlessly destroyed and regarded as a wilt producer. This procedure must be continuously applied to the present crop in Bihar and also to the seed obtained from Java. In a short time, the crop will be brought back to its old vigour and wilt in Bihar will become of small importance.

(2) Every possible means must be taken to improve the aeration of the soil. The protection of the aeration of the soil of the higher indigo areas is a matter of surface drainage. If we divide up the area by trenches as has been done at Dholi and get rid of the run-off at once, each field will have to deal with its own rain only and will not be subjected to surface drainage water. Such a system is bound to protect the plant and to assist it in resisting wilt. The improvement of the general drainage of Bihar as a whole

and the prevention of floods will act in the same direction.

The mere introduction of new seed from Java is of no value as a remedy for wilt. The crop raised from this seed is affected in a similar manner to that produced from local Bihar seed. The cultivation of indigo in Java has fallen considerably in recent years. According to the account of this crop given in van Gorkom's *Oost-Indische Cultures* (vol. 3, p. 18, 1913) the production of indigo fell from 14,677 maunds in 1903 to 1,613 maunds in 1910. This is confirmed by the experience of the Hon'ble Mr. Keatinge, C.I.E., Director of Agriculture of Bombay who visited Java in 1913 and who has kindly sent us the following information (Letter, dated Poona, August 28th, 1916):

"When I was in Java I was on the lookout for indigo seed for you, but was told everywhere that there was very little grown now in Java and none at all on an organized scale. I could not find that any of the Companies grew it, and the only place where I saw it grown was at Djokjakarta where a good deal is grown in small plots by natives for their own use. When I was there in December the crop was still young. From what I saw I feel fairly sure that it is no longer grown on a commercial scale or under skilled supervision in Java."

Importers of Java seed often comment on the difference in quality and germination power between that now obtained and the supplies of ten years ago. The seed now imported is raised by the natives who according to van Gorkom (p. 32) take no care in selecting their seed. When grown by the Dutch planters, the production of seed was a matter to which great attention was paid. It appears therefore that both in Java itself and also in Bihar the botanical constitution of the main crop has altered in a similar manner and is now largely composed of deep-rooting, late types. These late types, however, do not breed true, but give rise to a certain number of early quick-growing forms. By a careful continuous selection of these early types it is practically certain that the old Java indigo, which did so well in Bihar, can be recovered.

Of late years wilt has sometimes made its appearance in fields of Sumatrana indigo. The explanation of this occurrence is doubtless due to a change in the type of plant cultivated. It is well known that in recent years a good deal of seed has been brought from the Punjab and mixed with the Cawnpore type before sale to the planters. These North-West types are deeper rooted than the Cawnpore plant and are therefore more liable to wilt in Bihar. The remedy in this case is to preserve the old Cawnpore plant and to supervise the production and sale of the seed.

IV. THE CULTIVATION OF INDIGO.

The cultivation of indigo is largely a matter of soil-aeration. The aim before the planter is a simple one namely, the production of the maximum amount of indigo per acre in the shortest possible time. After the end of July, the crop is always liable to damage by wilt and floods so that it is a great advantage to force on the growth and secure the second cut during the latter part of this month. The directions in which the plant can be assisted in its work fall naturally under two heads—cultivation and drainage. These two matters will be considered separately.

Cultivation. It is in the cultivation of Java indigo that improved methods are particularly necessary. The preparations for sowing Sumatrana at the beginning of the hot weather have reached a high level with the means available and no very great room for improvement appears to exist as far as this species is concerned. In the preparation of the land for the Java crop however, insufficient attention is often paid to the aeration of the soil. As is well known, the Bihar alluvium becomes densely packed by the monsoon rains and is often on the moist side when the sowing time for this crop comes round in October. A thorough cultivation of the soil before sowing and the formation of a good aerated tilth have a wonderful effect on the young seedlings. Their root development is stronger, abundant nodules are formed and the plants come away well in late October and early November. Want of cultivation on the other hand, particularly when the soil is on the wet side, leads to a stunted crop very liable to attacks of *Psylla*. Planters will find it to their advantage to bestow more care on their preparations for sowing Java indigo for leaf and to bear in mind they are dealing with a leguminous plant whose future, as an indigo producer, depends on a copious development of roots and root-nodules.

The cultivation of both Java and Sumatrana indigo during the hot season is a matter to which adequate attention is only now being paid. During this period, two things are necessary—the removal of weeds (which rob the soil of moisture and minerals and check the branching of indigo) and the formation of a surface mulch of several inches of loose, dry soil to conserve the moisture and check burning. Even on the best managed estates it is doubtful whether the indigo is cultivated enough during the hot weather. It is still possible to see stretches of plant competing with weeds in land the surface of which is much too hard and firm to the tread. Formerly, indigo fields were hand-weeded but the results were not satisfactory and the expense was considerable. The crop can be weeded and the mulch of dry soil produced by means of the Canadian lever-harrow, the tines of which can be adjusted to suit

the stage of development of the growing indigo. Immediately the cover crop is removed in March, the young indigo should be cultivated with these harrows and, as the plants develop, a deeper and deeper mulch of dry soil should be produced. Weeds are at the same time pulled out and the *papri* is broken. About the beginning of May, the crop should be sufficiently advanced to stand cultivation with the spring-tine cultivator [1] by which a mulch of dry soil about three inches in depth can be produced. The effect of this cultivation is to stimulate growth, to remove weeds and to leave a thick mulch of dry soil. This soil mulch preserves moisture and checks burning and also serves to absorb all the early monsoon rainfall. The result is extremely rapid growth and the hastening of the time of the first cut.

After the first crop is taken, the indigo roots produce shoots for the second cut much more quickly if a branch is left to maintain the transpiration current. This is a great advantage as the sooner the second cut is taken the better. It often happens that wilt appears on the old branch as soon as the new basal shoots are well established. This has been referred to above and is merely a starvation effect and does not involve the wilting of the new growth.

After the second cut has been removed, the crop should be dug out and the land got ready for *rabi* crops. It does not pay to keep the old stumps for a seed crop as by this means the land becomes exceedingly foul with weeds and the quality of the seed so obtained is generally poor and often small in amount.

Drainage. As the well-being of the indigo crop, other things being equal, depends on the aeration of the soil, it follows that any means of protecting the porosity of the land from damage by rain and flood-water must prolong the life of the plant and increase the yield of indigo. One of the factors which destroys the tilth and cuts off the air supply to the roots is the rainfall. This we cannot control and it may sometimes happen that this factor alone will be sufficient to destroy the aeration of the soil and bring on wilt.

There are, however, two factors besides the direct rainfall which affect soil-aeration. These are the run-off (the portion of the rainfall not absorbed by the soil) and floods. The run-off (often referred to as surface drainage) is perhaps more detrimental to indigo than floods as the former damages the crop every year whereas floods occur only about once in four years. The run-off acts as extra rainfall and land subject thereto loses its porosity and therefore its power of maintaining its air

[1] The Canadian lever-harrows referred to can now be obtained from Messrs. Octavius Steel & Co., Calcutta, who are the Indian Agents for these implements. The five time, spring-tooth cultivator is sold by Messrs. A. Butler & Co., Muzaffarpore, and by Messrs. Volkart Brothers, Lyallpur, Punjab.

supply much more rapidly than fields which have to deal with their own rainfall only. The control of the run-off is a simple matter and can be achieved by the Pusa method of surface drainage now to be seen in operation on the Dholi estate.[1] This system consists in dividing the *zeraits* into suitable blocks, each about five bighas in extent separated from one another by trenches provided with grass borders. The run-off of each field passes over the grass borders into the trenches and is led to the drainage lines. Fields at a lower level are thus protected and have to deal with their own rainfall only. Incidentally, the fine soil is retained on the land and such fields level themselves and rapidly increase in fertility.

Floods affect the well-being of the indigo crop in several ways. Complete submergence of the plant for any length of time naturally destroys it. On light poor lands, where the nodule cycle is important, the flooding of the land either kills off the indigo at once or leads to wilt. Submergence of the land in which the indigo depends on the nitrate nitrogen cycle may not in all cases, as explained above, destroy the crop. Even where the high lands are not flooded, any great rise in the water level at once affects the sub-soil and renders it much moister than before. The affected indigo may not actually wilt but it often begins to change in colour and to drop its leaves. An interesting case occurred at Pusa in October 1915 when the late flood markedly affected the amount of moisture in the sub-soil and led to the production of much yellow leaf followed by leaf-fall. Floods are also detrimental in interfering with the efficiency of a surface drainage system by blocking the outfalls and so preventing the draining away of the run-off.

The prevention of floods is naturally a more difficult matter than the control of the run-off. It is, however, of great importance to the future of the indigo industry and to the agricultural development of North Bihar. This tract of country consists, as is well known, of a series of alternate ridges and low-lying areas which run roughly parallel to the rivers. A section at right angles to one of the rivers would pass through a series of these raised folds and low-lying depressions. The indigo factories occur on the ridges and rice is cultivated in the depressions. During the monsoon, the sub-soil water level rapidly rises and the rice areas fill up with storm water. The monsoon water-level is now often so high that only the ridges remain above water. When a flood comes down from the hills under these conditions, the water-level rises still more and some of the ridges with their indigo fields go under water and are destroyed. No local system of surface drainage, however perfect,

[1] For a fuller account of this system of surface drainage and of its advantages the reader is referred to Pusa Bulletin 53.

is of any avail against such floods. There is total submergence for some days till the overworked drainage lines can again lower the water-level. Serious as is the occurrence of these floods, a still more ominous circumstance is the fact that the high-flood level is slowly rising at the rate of about three inches a year. The result is that the air-spaces in the soil become more and more replaced by water and the area of indigo killed out increases. Experienced planters say that this continuous rise in the flood-level is caused by embankments (canal, rail and road) which interfere with the natural drainage of the country and indirectly silt up the water-ways. There can be no doubt that they are correct and that in the development of North Bihar far too much attention in the past has been devoted to communications and that little or nothing has been done to maintain and improve the water-ways. The rivers and drainage lines in an agricultural country are far more important than roads, railways or canals. The rivers and their tributaries are the natural drains of the country which carry off the surplus water and prevent the land becoming a swamp. Anything which interferes with this river action in the monsoon helps towards swamp conditions in two ways—by holding up water and by causing silt deposition in the channels. When the flow of a river is checked, silt begins to deposit and the bed is raised. The river thus becomes less efficient and as this proceeds it overflows its banks more frequently. In the construction of practically every bridge over the small rivers and drainage lines in North Bihar, too much attention has been paid to economy. In erecting these bridges, an earthen embankment is generally thrown across from each bank of the drainage line and a little bridge is put in in the middle to save iron-work. The result is that the high-flood water-way is partly obstructed; water is held up longer than is necessary while the deposition of silt slowly blocks up the channel. Besides such embankments, the Tribeni canal, which crosses the drainage lines near the Nepal frontier and sometimes converts the country to the north into a huge reservoir, is said to be a potent source of mischief. The bursting of this mighty artificial lake is often too much for the overworked rivers and, in 1915, great damage was done.

The remedy for this state of things is the immediate construction of a drainage map for the whole of North Bihar on which the various drainage lines and the impediments to the free flow of water are accurately recorded. With this map as a basis, obstructions to the natural flow of water can be removed and the Executive will possess a powerful means of control in the future. No new machinery is immediately necessary for dealing with this matter. The District Boards possess the funds and Embankment Committees exist for dealing with such subjects

On both of these bodies the indigo planters are strongly represented. The improvement of the general drainage of North Bihar is the foundation stone on which the fabric of a rejuvenated natural indigo industry can be reared.

V. SEED SUPPLY.

Java indigo. The importance of a reliable source of seed of Java indigo needs no explanation. If the supply can be produced locally a large amount of money will be saved and a great source of anxiety to the planters will have been removed. Now that the improvement of the Java crop by selection is in progress, it is more than ever desirable to discover methods of seed growing which are quite independent of the season and which can be taken up on the estates themselves.

Considerable attention has been paid to this matter at Pusa. The first point that has been proved is that seed growing must be regarded as quite separate from ordinary indigo cultivation and that the former practice of keeping on old indigo for seed must be given up. A special seed crop should be sown in early August which afterwards can be kept for lead. In ordinary years, as has been demonstrated at Pusa and at Dholi, this operation presents no difficulties and exceedingly fine crops of well-filled seed can in this way be obtained. As no setting takes place unless the flowers are visited by bees, the seed crop must be well-spaced and the plants allowed to branch. If grown in the ordinary way, the plants are much too close together and only a little seed is formed on the tips of the branches.

In a year of heavy July and August rainfall combined with floods, the matter is, however, not so simple. Such a season occurred in 1915 when, on many estates, the August sown seed crop was more or less a failure. As the experience obtained in that season furnishes valuable confirmation of our views on the importance of soil-aeration in indigo growing, the facts of the case must be stated in some detail.

The monsoon of 1915 in North Bihar was heavy and well-distributed and, in addition to the rainfall, there occurred a series of floods which, on most estates, cut short indigo manufacture and killed out large areas of the crop. The weather during the first half of August—the period when Java indigo has to be sown for seed—was very wet and few breaks occurred. The almost continuous rainfall after the seed crop was sown, coming as a reinforcement to the heavy falls in July and to the floods, so consolidated the soil and interfered with its aeration that on a comparatively few estates only did the seed crop do well. It was only in cases where the surface drainage was good and the natural aeration of the soil was above the average that Java indigo sown for seed was able

to grow normally and produce an average outturn. On the heavier soils in the sub-montane tract and on the lighter lands which had been flooded previous to sowing, the soil-aeration was so interfered with that the seed crop was attacked by *Psylla* and wilt and proved a complete failure.

At Pusa, a normal yield of seed was only obtained on two of the highest plots in the Botanical Area. The indigo on these areas, which were perfectly drained, behaved as in a normal season. Three plots at a lower elevation did not do nearly so well. After the last flood in October, the soil and sub-soil became much wetter (due to lateral percolation from the Gandak), the leaves began to turn yellow and leaf-fall commenced. The crop was saved from destruction by a deep cultivation with the *kodar* which gave the roots the necessary air. The late flood kept the sub-soil water high and so prevented the soil-aeration which follows the usual fall of the ground water in September. The three plots in question gave a moderate yield of good seed but it was not till the hot weather began in February that the foliage really became normal. This experience as well as that on many estates shows how much the prospects of the seed crop depend on the rainfall and on the fall of the ground-water towards the end of the monsoon.

In the case of Java indigo sown for leaf in early October on the higher lands, quite different results were obtained. After sowing time, little or no rain fell till March and so there was nothing to interfere with the natural aeration of the soil. In many cases, this leaf crop gave small quantities of excellent seed in February, a phenomenon which does not often occur in years when the normal amount of cold weather rainfall is received.

This experience agrees, in all respects, with the results of the various experiments in growing Java indigo for seed at Pusa. Seed formation, other things being equal, is a matter of soil-aeration. If ample air for the roots is provided a full crop of seed is obtained. If heavy and long-continued rain after sowing interferes with growth, the crop is bound to be below the average.

It has been shown that in ordinary seasons August sowings on high, drained land are all that is necessary to secure the seed crop. Some means, however, must be discovered of obtaining seed in wet years like 1915. Several methods of accomplishing this result are being tried. If the seed crop is sown fairly thickly, it might easily be possible by means of the lever-harrow on the young indigo to increase the aeration very considerably during the breaks in the rains. As soon as the crop is strong enough towards the end of September, the spring-tine cultivator could be used to increase still more the depth of the aerated soil and in doing

so half of the remaining crop could be removed. After the *hathia*, the land could be tunnied with the *kodar* (mattock) after which air would find its way to the deeper layers of the soil. In ordinary years, such a treatment does the seed crop a great deal of good. In a year like 1915, it made all the difference between success and failure and the expense was well repaid.

Besides cultivation during the early stages of the seed crop, the possibility of improving the aeration of the soil by means of *thikra* remains to be considered. At Dholi, it was noticed in 1915 how much faster the October sown indigo developed in a field in which *thikra* occurred. The growth was twice that on the land which contained no potsherds. At Pusa very good results have been obtained on such land and it might easily pay to make special *thikra* fields for seed indigo. Experiments on this point are in progress both at Pusa and Dholi and it is expected that the first set of results will be obtained next cold weather.

In addition to adding *thikra* to the land, the provision of sub-soil drainage may prove to be necessary in very wet seasons. Preliminary results obtained at Pusa indicate that this method is likely to be successful. The method is being investigated and as soon as possible will be tried on an estate scale.

A further point connected with seed growing is under investigation. It has been observed in the past that indigo forms the best seed on rather poor land and that rich soil is a disadvantage. Similar observations have been made on gram and other leguminous crops. Soil-aeration for these crops is of the greatest value in seed formation but rich soil, even when combined with improved aeration, leads to rank growth and a poor yield of seed. If, as we suspect, indigo behaves in the same way the point will be important as many of the indigo *zerats* are on the rich side due to extensive dressings of *seeth*. The experiments on this point at Pusa ought to yield definite results this year.

The storage of Java seed offers an obvious solution for tiding over an unfavourable year like 1915. In ordinary years when crops of at least twelve maunds to the acre can be grown, it would be easy to dry the seed and seal it up in sheet iron bins of the Pusa pattern.[1] Such seed would keep for several years and thus estates would be independent of the season.

Sumatrana indigo. Some attention has also been paid at Pusa to growing Sumatrana indigo for seed. Two varieties were tried—Madras and Cawnpore—and both were sown in August. In each case good

[1] For a description of these bins see *Agricultural Journal of India*, vol. X, p. 299, 1915. They are now manufactured by Messrs. Burn & Co., Calcutta.

seed was produced but the yield was small. The prospect of growing the seed of this species at a profit in Bihar does not appear very promising. The seed supply will become important however if any considerable improvement in this species is obtained by selection.

The regulation of the present seed supply of Sumatrana indigo from the Cawnpore region is a matter of importance. Some system of inspection of the fields and the purchase of the whole crop by the Bihar Planters' Association would prevent adulteration with poor quality seed from the North-West and would also help to regulate the price. This is primarily a matter for the planters themselves. It concerns the investigator, however, as well for until the seed supply of Sumatrana is properly controlled, there is not much point in attempting to improve this crop by selection.

VI. THE IMPROVEMENT OF INDIGO.

1. Java indigo.

The introduction of Java indigo. The introduction of the Java plant into Bihar agriculture in 1898 by Mr. H. A. Baily was an important event in the history of the natural indigo industry. This species is much richer in indigo than Sumatrana and also gives a higher weight of leaf to the acre. Until it became affected by wilt in recent years, great hopes were entertained that by its means the decay in the Bihar indigo industry could be arrested and the competition of the synthetic product successfully withstood.

Natal indigo. Java indigo is said to have been introduced into Java from Natal where it was found growing in the wild state. Java indigo, as grown by the Dutch planters, is however quite a different plant from the wild indigo of Natal. In 1913, through the good offices of Mr. F. B. Smith, Secretary of Agriculture to the Government of the Transvaal, the seeds of single plants of the wild indigo of Natal were separately collected in that country for growth at Pusa. In this way, a strict comparison was possible between the real Natal indigo and the Java plant. The seeds of the various Natal plants were sown separately in rows next to next so as to determine to what extent the progeny of a single parent showed any marked variation. The rows were remarkably uniform in themselves and there were no great differences to be observed between the various lines. Natal indigo proved to be erect in habit with little-branched, green stems and the foliage was somewhat sparse. The reddish stems and leaves and the much-branched habit of many of the types found in Java indigo were entirely absent. As regards susceptibility to *Psylla* and

wilt, the Natal plant showed far less resistance than the Java cultures growing side by side. This fact, combined with its erect habit and poor branching left no doubt that, from the agricultural point of view, Natal indigo is unsuitable for cultivation in Bihar. This agrees with the experience of several of the Bihar indigo planters themselves.

Constitution of the Java crop. Java indigo is by no means so uniform as the Natal plant. It consists of a mass of forms differing in habit (from erect to much branched types) : in colour of the stems and foliage(greenish, intermediate and reddish) ; in size and shape of leaflets, in time of flowering and also in root-development. The range is extraordinary and the occurrence in the mixture of forms resembling Natal indigo lends colour to the idea that Java indigo arose from a cross between the Natal plant and the species formerly cultivated in Java. At first sight, Java indigo appears to afford an ideal selection ground for the plant-breeder. Before, however, the question of improvement by selection can be considered, the methods of pollination and of fertilization in this species must be studied in detail. It is only on such evidence that correct methods of improvement can be founded.

Pollination. The method of pollination of Java indigo was studied by Parnell at Sirsiah and in the last report of that station he described the results of this investigation as follows :—

"Examination of the flower of *I. arrecta* reveals a mechanism designed to ensure extensive cross-fertilization. The style projects through the ring of anthers and carries the stigma into the closed apex of the keel where it is protected from contact with the pollen liberated lower down in the keel by the bursting of the anthers shortly before the flower opens. By carefully exposing the stigma of an unsprung flower one can see that it remains free from its own pollen in almost every instance. If the spring mechanism is not released the flower remains in this condition for several days when it begins to fade and the pollen may gain access to the stigma and produce self-fertilization. This latter event however occurs rarely : this may be due partly to the fact that the pollen does not always reach the stigma and partly to the fact that the pollen of an old flower possesses considerably less germination power than when it is fresh, a fact readily demonstrated by germination tests done in an agar solution containing 15 per cent. cane sugar.

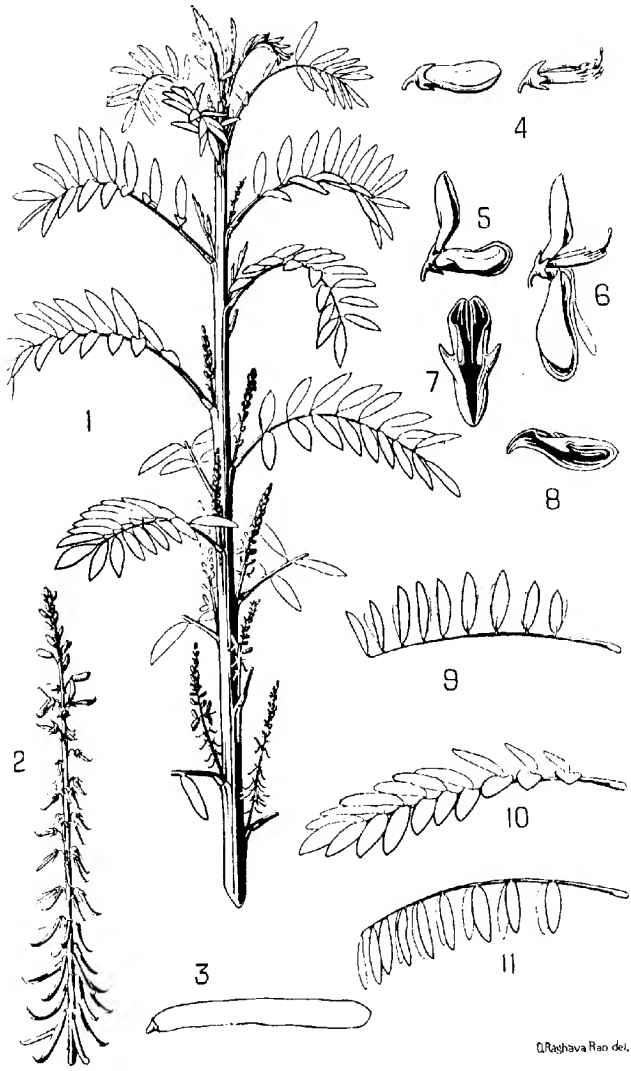
Normal fertilization appears to be brought about through the agency of insect visitors. In the young open flower, a state of tension exists between the ovary and the keel. The latter exerts a strong downward pressure on the ovary and is kept in position by means of a fold of its free edge on each side, the two folds coming together for a short space

over the ovary about the middle of its length. Two projecting spurs of the keel, one on each side level with the folds, support the wings as a level platform over the keel. When an insect alights on this platform the spurs are depressed, thereby separating the folds and releasing the ovary. The wings and keel spring down, owing to a sudden bending at their base, till they are about at right angles to the ovary which has jerked suddenly upwards. The stigma comes into immediate contact with the under side of the insect which is also covered with a cloud of pollen; in this way the stigma receives a mixture of pollen from the flowers already visited by the insect. This operation may be observed very readily in the field, being effected most commonly by *Apis florea* and *Halictus gutturosus*, two common Indian bees, both of which visit flowering indigo plants in large numbers."

During the past three years we have examined the flowers of Java indigo in detail and our observations confirm and extend those of Parnell. The details relating to the flowers and the method of pollination can be seen in the Plate. There is no doubt that pollination by means of bees is the rule in this crop and that in the absence of these insects little or no setting takes place. To prove this, a number of large healthy indigo plants, which had been grown from seed sown at the end of August, were covered with frames over which mosquito netting had been stretched. The plants were put under the frames before any flowers had opened and the bases of the frames were sunk a few inches in the earth to ensure the complete exclusion of insect visitors. In all cases practically no pods formed, the flowers remaining open for a few days and then drying up. The covered plants grew, if anything, better than those outside. The ordinary uncovered plant set seed in abundance and the contrast in this respect between the covered and uncovered plants was most striking. In each of the covered plants one branch was allowed to grow outside the net, an arrangement having been made for this purpose which excluded insects. The branch growing out into the free air in all cases set seed, thereby proving that the failure to set seed on the part of the covered plants was not due to any weakness of the plant itself but solely to the exclusion of insects.

The absence of more than very occasional setting under nets although the stigma is often in contact with its own pollen, is not

Description of Plate.—1, a flowering branch of Java indigo. 2, a complete inflorescence. 3, a ripe pod. 4, a flower bud showing the relative position of the anthers and stigma just as the pollen is liberated. 5, a fully opened flower. 6, a sprung flower. 7, the keel seen from above showing the projecting spurs and folds. 8, half the keel seen sideways showing the fold which keeps the young pod in place. 9, the position of the leaflets at midday. 10, a leaf in early morning. 11, the position of the leaflets at dusk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confined to Java indigo. It is a common occurrence in that group of the *Leguminosae* in which fertilization is largely dependent on insect visitations. Sumatrana indigo behaves in exactly the same manner. Another interesting local example is *sanai* (*Crotalaria juncea*). In such cases for fertilization to take place, it is not only necessary for pollen to come in contact with the stigma but the stigma must itself be stimulated by rubbing such as occurs when the indigo flower explodes and the stigmatic surface strikes somewhat violently the underside of the body of the bee.

Natural cross-fertilization. The fact that practically no setting takes place under nets and that for seed formation to occur the visits of bees are necessary, points to the existence of extensive natural crossing. We should expect to find that the crop is a mass of complex hybrids which do not breed true from seed. In order to verify this point and also to compare the progeny of single plants, the seed of a large number of individuals of the 1913 crop was collected separately and sown singly in lines, next to next, the following August. None of the plants bred true but gave rise to mixed cultures, thereby confirming the occurrence of extensive natural crossing in this crop. Variation due to crossing took place in many obvious characters such as the colour of the stem (greens, intermediates and reds), time of flowering, habit of growth, size of leaves, amount of total leaf surface and rapidity of growth.

Vigour of plants from self-fertilized seed. In all crops where cross-fertilization is the rule and little or no setting takes place in protected flowers, it is particularly necessary to determine whether or not there is any lack of vigour in the plants raised from self-fertilized seed. So far as the evidence obtained at Pusa goes, the indications are most definite that Java plants raised from self-fertilized seed, even in a single generation show a marked falling off in size and general vigour. If an attempt were made to purify the Java hybrids and to obtain a plant breeding true with high indican content, the experiment would, in all probability, fail in a few years on account of self-sterility. Equally weak plants are generally obtained if a similar attempt is made in crops like maize. Experience teaches that in such cases there is no advantage to be obtained in trying to avoid crossing and to secure plants breeding true to type by continued self-fertilization. Such attempts at in-and-in breeding fail through loss of vegetative vigour. It is better to control crossing in such cases as Java indigo than to attempt to prevent it.

Indican content. One of the factors that must be considered in the improvement of Java indigo by selection is *indican* content. That the various individuals constituting the mixture known as Java indigo

differ considerably in *indican* content seems exceedingly probable on general principles and is confirmed by Parnell's statement that these differences actually do occur in the field. The profitable utilization of such differences however is quite another matter. What is the meaning of *indican* content? Considered physiologically, the *indican* in the plant represents roughly the difference between the total nitrogen assimilated and that used up for growth. *Indican* content, as we know, varies greatly with the environment and is usually highest in slow growing plants. Other things being equal, we should expect a higher *indican* content in slow growing, late types than in rapidly developing early sorts. This is supported by the trial of a rapidly growing type of Java at Dholi this year which gave somewhat less indigo per 100 maunds than the general crop but made up for this by an increased yield of plant per acre. Conversely, the late Madras type gave more *indican* per 100 maunds than the early Cawnpore Sumatrana. Bergtheil (Sirsiah Report for 1906-07, p. 19) found that the *indican* content in the slow-growing Multan type of Sumatrana was higher than in the rapidly-growing Delhi-Cawnpore variety.

In selecting on the basis of high *indican* content for Bihar conditions we are likely to encounter a serious difficulty. The plants richest in *indican* will probably be slow-growing, late kinds which will not fill the planters' carts and which may be caught by wilt and floods in the second half of the season. What the planter wants is a rapidly-growing Java plant which is a cart-filler and which can make the most of the early safe monsoon period. The investigator, in following the line of high *indican* content, is more than likely to fail. He may succeed in getting a type high in *indican* but it may be of no practical advantage to the planter. In a country like India where the season is everything, experience teaches us that it is best to play for safety and not to take risks. It is always advantageous to cultivate types which will ripen well within the season and to avoid late kinds which only succeed now and then. Every planter will agree that the period June and July is far more important in indigo manufacture than August and September and that the sooner the first two cuts are carted the better. The planter's object in growing indigo must at this juncture be clearly kept in mind. It is to secure the maximum amount of indigo per acre, *not to grow the type which gives the highest yield per 100 maunds of green plant*. The highest yield per acre under Bihar conditions may easily be obtained by types which are by no means the highest in *indican* content.

Methods of selection. In the improvement of plants everything depends on the adoption of the right method. The method or methods in any particular case depend on an accurate understanding of the facts

dealing with pollination and fertilization and a correct appreciation of all the working conditions, botanical as well as agricultural.

In the present case it will be an advantage, before dealing with the actual methods which can be adopted, shortly to recapitulate the working conditions. These are:—

(1) Cross-pollination by bees is the rule and little or no setting takes place in the case of protected flowers. Artificial self-pollination is difficult and does not yield much seed.

(2) The crop, as ordinarily grown, consists of a mass of complex heterozygotes, that is, of plants which do not breed true.

(3) The seed of self-pollinated flowers gives rise to offspring lacking in vigour compared with the plants raised from ordinary seed. The occurrence of self-sterility is practically certain in Java indigo.

(4) The types composing the crop vary greatly in rapidity of growth and time of flowering. Some develop quickly and flower early, others grow much more slowly at first and only begin to flower towards the end of the season. This range in time of flowering is correlated with the development of the root-system—the early sorts are shallow-rooted while the late kinds are deep rooted.

(5) The types vary in *indican* content and there is evidence for believing that the early kinds contain less *indican* per 100 maunds than the late slow-growing kinds.

(6) The best method of obtaining seed of Java indigo is by August sowings and not by keeping on the October sown leaf crop for seed.

(7) The time during which the work dealing with chemical selection has to be carried at is very limited. This must be done during early October before flowering begins and the plants tested must be in a similar stage of development.

A study of the working conditions discloses the fact that the improvement of the Java crop by selection will not be easy. Methods of selection such as can be applied to crops like wheat in which self-pollination is the rule and in which cross-pollination is rare are out of the question. Methods which can be adopted in crops like tobacco which set seed freely under nets are equally eliminated. Selection which depends on artificially selfing protected plants is put out of court by the occurrence of self-sterility. One set of methods only remains—those which depend on the control of natural crossing. In many respects,

these are the least satisfactory of all the methods of selection as the process to be effective must be continuous.

Three methods of selection are possible in Java indigo, in two of which considerable progress has already been made at Pusa.

(1) Selection of mixed early types. As has already been indicated in this report, the advantages of rapid maturity are likely to outweigh all other considerations. If, therefore, the seed of a large number of promising early individuals is collected separately and sown in lines, a comparison can be made among the offspring as regards earliness, vigour and rapidity of growth, branching power and general agricultural fitness. The best cart-fillers can thus be picked out and the weak lines eliminated. The lines which remain can then be gone over and all the weak and late-flowering plants removed. The seed of the remaining plants is now mixed and sown on the large scale. Careful elimination of unsuitable plants is carried out before flowering begins and a second elimination a few weeks afterwards will serve to remove all late flowering individuals. When sufficient seed has been obtained, the early mixture can be given out to estates. The seed crop should be subjected to similar careful selection every year. This can easily be done on the estates and in the course of two or three years the mixture will tend to breed closer and closer to the desired type. A promising early mixture has been obtained in this way at Pusa which will soon be ready for a trial on an estate scale. There is, however, no reason why every planter could not begin work himself on these lines and develop an early mixture suited to the condition of his estate. About a hundred or two early flowering plants should be selected from the ordinary mixed crop and labelled. The seed of these should be mixed and sown the following August on a field scale and all late and unsuitable plants destroyed. It is more than probable that such a mixture, besides giving more indigo will also prove considerably more resistant to wilt than the present Bihar crop. We should not be surprised to find that this method, rough and ready as it is, will give better results than either of the two remaining methods which will now be described.

(2) Selection of single early types. The only difference between this method and that just described is concerned with the number of original parent plants. In the present case, the selection is started from one plant. The choice is made after observing the produce of about fifty promising individuals grown in lines side by side. The two best cart-fillers are selected, all late and weak plants eliminated and the seed of each is sown separately on a large scale. Every year the process is repeated and most of the aberrant types removed before flowering. Any late plants which have escaped are

destroyed later on and in this way the selection is kept as near to type as possible. As soon as enough seed has been obtained, the two best single selections are tried on an estate scale. Two of such selections (types 11 and 15) are now being tried on the Dholi estate, care being taken to grow the seed of each in fields about two miles apart. Although these types are rapid growers and show considerable promise they are not likely to prove such good cart-fillers as the selection from the mixed early types. A mixture is likely to make the best use of the available space both above and below ground, by the interlocking of the branches and roots. The individuals of a single type get into each other's way much more than those constituting a mixture.

(3) Chemical selection. The success which has attended chemical selection in the case of the sugar beet is one of the reasons why both planters and investigators have hoped for similar results in Java indigo. The circumstances of the two cases, however, are widely different. While we consider that an attempt should be made to improve Java indigo by chemical methods, nevertheless we feel that planters should be prepared if not for actual failure at any rate for somewhat meagre results. The difficulties which attend the application of this method to indigo under Bihar conditions are considerable. In the first place, the plants likely to contain the highest *indican* will probably turn out to be late, deep-rooting sorts liable to wilt. The early, rapidly-growing types seem to be the most desirable kinds to grow and chemical selection ought only to be applied to these forms, at any rate at the beginning. In the second place, the chemically selected parents will have to be grown under nets and allowed to cross among each other by means of relays of pollen-free bees introduced into the cages. In the third place, the time available for analysing the parents is very small as the process must be completed before flowering begins. Unless the range in *indican* content of the individuals which remain after all unsuitable plants have been removed is considerable, chemical selection becomes impossible. We know that the individuals of a mixed crop vary widely in *indican* content. We do not know the range among the members of an early type left after the weak and unsuitable individuals have been removed. Chemical selection does not arise until a wilt-resistant type of Java indigo has been selected and tested on the estates. Once this has been obtained, an attempt can be made to improve it by chemical selection.

It must not be forgotten that a good deal of work was done by Bergtheil and Parnell at Sirsiah on the improvement of the Java crop by chemical selection. This is described in the last Sirsiah Report. A set

of seeds of the selected plants, which had been isolated on account of their high *indican* content, was handed over to us when the Indigo Research Station was closed. These seeds were sown at Pusa where they proved to be slow-growing, deep-rooted types. They were destroyed by wilt and did not set any seed. Side by side, the early, rapidly-growing Java selections grew vigorously.

It is well to bear in mind when considering the question of chemical selection that the Bihar method of raising seed from the Java indigo grown for leaf amounted, to all intents and purposes, to the selection of plants high in *indican*. By this process, the late-flowering, deep-rooting types were preserved and the early forms suppressed. The result of this unconscious chemical selection was to bring the natural indigo industry to the verge of ruin.

2. Sumatrana indigo.

The improvement of Sumatrana indigo by selection is likely to prove even more difficult than that of the Java crop. Sumatrana does not yield so much seed as Java when grown under Bihar conditions.

The general methods of pollination and fertilization in Sumatrana closely resemble those already described in the case of Java indigo. The details with regard to the structure of the flower, the method of pollination and the infrequency of setting under nets are very similar in both species.

The methods of selection possible in Sumatrana are very much those above described in detail in the case of the Java plant. There is, however, less range in form in the case of the Cawnpore plant—the type which appears to be the most favourable selection ground. The indigos from North-West India are generally agreed to be hardly worth growing in Bihar. The Madras type is more promising both from its branched habit and higher *indican* content but it does not grow well under Bihar conditions. As it matures later than the Cawnpore plant, its root-system is deeper and in this way probably be found the reason for its unsuitability for general cultivation in Bihar.

In 1914, a small quantity of Madras Sumatrana was obtained from the Cuddapah District. This type was tried at the suggestion of Professor A. G. Perkin, F.R.S., who found in England that it contained more *indican* than Bihar Sumatrana. It was sown in August for seed by the side of the ordinary Cawnpore Sumatrana. Although later in flowering, the Madras type grew and branched exceedingly well and appeared to be very promising. Enough seed was then obtained from Madras for a full vat test on the Dholi estate the following year. The result was not promising. The yield of indigo to every 100 maunds of

plant was very satisfactory and better than the Cawnpore plant. The produce per acre, however, was disappointing and the crop did not grow well under monsoon conditions. The Madras type being deep-rooted probably requires better soil-aeration than is possible under Bihar conditions. The result, however, is of interest. It supports the view that lateness, deep-rooting and high *indican* content go together and that this combination is of no value in the Bihar alluvium.

Should it be found possible by selection to improve the Cawnpore plant, the difficulty of the seed-supply will still remain to be overcome. Sumatrana seed is not grown in Bihar and as far as can be seen at present it is likely that it will be cheaper to import seed from the Cawnpore region than to grow it locally. What will be the fate of an improved Sumatrana when grown by cultivators who cannot be supervised? The chances are that it would speedily become mixed with country seed and therefore lost to the Bihar industry. Until some efficient means of controlling the production of Sumatrana seed has been devised it seems hardly worth while to expend the labour needed for selection work in this crop.

One line of investigation however must be kept in view namely, the possibility of crossing a high yielding Java type with a good strain of Cawnpore Sumatrana. The object would be to evolve a new type of Java with a shallower root-system and more rapid growth for Bihar conditions. Such an improvement depends on whether Java and Sumatrana can be crossed. Attempts have been made in this direction by two of the assistants at Pusa but without success. As soon as opportunity permits, we propose to examine this matter ourselves.

VII. INDIRECT METHODS OF IMPROVING INDIGO.

Apart from the well known value of *seeth* in Bihar agriculture and the fact that we are dealing with a leguminous plant, there is one aspect of indigo cultivation to which insufficient attention has been paid. This is the place of indigo, particularly of Java indigo, in the rotation. The deep root-system of this crop acts like *rahar* and is a most efficient subsoil plough for the Bihar alluvium. It not only tends to conserve the supply of organic matter but also opens up the sub-soil and helps to keep the land in condition. If the cultivation of Java indigo were given up on the estates, planters would have to place their high lands periodically under *rahar*, the value of the seed of which is small. The advantage to rice of a previous crop of Sumatrana is recognized and several planters have observed the improvement in the rice which results from this rotation.

In the second indigo report, reference was made to two indirect methods of improving the indigo industry, namely, the provision of a more valuable cover crop for Java indigo and the better utilization of *seeth*. Further work has been done in both these directions.

Cover crops. On certain soils in Bihar, it appears desirable to check the development of the Java crop during the cold weather and to begin the hot season with a somewhat late plant. This is accomplished by growing a cover crop such as wheat which not only checks the indigo and provides revenue but also keeps down weeds. Possibly on very strong soils which hold water well and in localities where the conditions are such that little burning takes place in the hot weather, it may be an advantage to grow a pure indigo crop and to force on growth for early manufacture so as to secure a second and possibly a third crop while *mahai* is still possible. Whether or not a cover crop is desirable in the case of Java indigo is likely to be settled by local experience. The danger of a cover-crop is undoubtedly to be found in the possible interference with sufficient light for the young indigo. If the cover-crop is too rank, too much light will be cut off and the indigo will suffer. This is likely to happen with any kind of wheat (unless sown thinly) on strong soils.

In cases where a cover crop is found desirable there can be no question that a rapidly maturing wheat with little foliage like Pusa 4 is suitable for the purpose. For some years on the Dholi estate, good crops of this wheat have been grown with Java indigo and, provided the stubbles are thoroughly harrowed afterwards, the succeeding indigo crops develop well in an average year. The harrowing, however, is essential and it is best to get this done immediately the wheat is cut and the surface soil is still soft and moist.

The value to the planter of a *rabi* cover crop like wheat depends partly on the existence of a ready market. Fortunately Pusa 4 is an early kind with good grain qualities and therefore likely to find favour in the Calcutta mills. To test this, a full scale milling test was arranged last April at the Hooghly Flour Mills which are managed by Messrs. Shaw, Wallace & Co. The parcel of 350 maunds milled was grown partly on the Benipore estate and partly at Dholi. The Manager of the Hooghly Mills (Mr. H. G. Taylor) has kindly sent the following report for publication (Letter dated Ramkristopore, June 24th, 1916):

"Both lots of wheat received were quite up to the standard of the sample sent from Pusa, clean and of uniform grade, and contained not more than one and a half per cent. refraction. I had a test taken of

the natural moisture content and this worked out at 11 per cent. this high percentage being due to the more humid atmospheric conditions then prevailing.

I find Pusa 4 is capable of absorbing water in larger quantity than is the case with the ordinary varieties we have to deal with and this appreciably enhances its value. During the milling process, the semolina and middlings separated very freely from the bran, and the yield of the former was much higher than is ordinarily possible, the quality was also correspondingly high.

In the actual reduction of middlings to flour there was an entire absence of what we describe as "wooliness" or "softness" with the result that the dress out of the centrifugals was very free, the flour quite lively to the touch, and the separations all that could be desired.

I presumed from the appearance of the wheat that the bran percentage would be low and this turned out to be the case for it was 3 per cent. below our normal. With the experience gained, and a larger quantity of this wheat to handle, I believe a still lower bran percentage would be possible.

On testing the flour by the Pekar test it turned out of a greyish white (the native of India prefers his flour to have a slightly yellow tint); the colour may improve by an additional moisture content. Under the doughing test, the flour showed great tenacity thus indicating the presence of gluten of high quality and quantity; the following figures show the percentages of gluten content, wet and dry, as compared with our ordinary quality of flour.

	Wet.	Dry.
Pusa	42·3	15·75
Ordinary	32·6	11·1

The drying was carried out in a Hearson electric oven at a temperature of 100°C. for five hours.

The last and most conclusive test of all has been the baking test; it is in consequence of an unsatisfactory baking test carried out a fortnight ago that the presentation of this report has been delayed, and this result was due to the incompetence of the baker I had then engaged. However, I have now a good man, and he has just turned out a batch of the finest bread I have ever seen in India: the loaves are equal in appearance to the Manitoba and Pusa 4, illustrated in your "Milling and baking qualities of Indian wheats" and is in decided contrast to the corresponding loaves made from our ordinary superfine, although that is also of very high quality. The texture of the bread is very uniform and it possesses a distinctly agreeable flavour; my baker speaks highly of it and states that it is the best flour he has ever handled.

I have now concluded my report and trust that I have made myself sufficiently clear and intelligible. If there are any other points you would like information upon please do not hesitate to write and I shall be most willing to assist you to the best of my ability."

It will be seen that the results of the trial are very satisfactory and that the Calcutta Mills are likely to buy up any quantity of this wheat produced in North Bihar. There is bound to be a considerable demand for Pusa 4 for seed purposes for certain tracts in Central India and in the United Provinces where this wheat is being taken up by the cultivators. The planters growing Pusa 4 in bulk will therefore have no difficulty in disposing of this wheat at remunerative prices.

The efficiency of seeth. As is well known, *seeth* is an excellent manure for tobacco. Its value, however, depends on its power of aerating the soil as well as on its chemical composition. Evidence has been obtained at Pusa that small pieces of tile (*thikra*) when added to tobacco lands also act as an efficient aerating agent. During the past year it was found that *sanai* used as a green-manure on a *thikra* plot gave twenty-four maunds of cured cigarette tobacco to the acre which fetched fifteen rupees a maund. It is clear that if the experiments in progress prove that it will pay to dress portions of the factory *serais* with *thikra*, such lands will need much less *seeth* than is now customary to apply. The experiments on this subject have now reached an estate scale and the results will be published as they accumulate.

QUETTA,
August 8th, 1916.

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